Performance of Vehicle-to-Vehicle Communication using IEEE 802.11a: A Measurement Study

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***Abstract*— V2V (Vehicle to Vehicle), V2I (Vehicle to Infrastructure) and ITS (Intelligent Transportation System) is the approach to increasing the safety of the transport system. VANET (Vehicular Ad-Hoc Network) is a version of MANET (Mobile Ad-Hoc Network) in which Vehicles act as active nodes of the network. VANET is a highly mobile system. In this paper, a real-time mobile measurement setup was established to simulate a V2V communication scenario in a suburban region using the IEEE 802.11a communication standard in 5 GHz band to evaluate various Quality of Service (QoS) parameters, such as throughput, delay end-to-end and packet loss in situations where vehicles are moving in opposite directions and in the same direction with different relative speeds between on board units. The main discovery of this paper are that the transfer rate is higher when vehicles are approaching in opposite directions and falls immediately when they cross and start to move away regardless of speed.**

Keywords—IEEE 802.11a, vehicle networks, throughput

I. Introduction

Vehicle traffic is one of the biggest problems in big cities. Getting around has become a daily challenge for thousands of workers in the main metropolitan areas due to congestion caused by various factors such as accidents, construction works or simply the excess of cars on the roads. Congestion reduces the efficiency of transport infrastructure and increases travel time, air pollution and fuel consumption.

Intelligent transport systems (ITS) are information and communication technologies that have attracted a lot of attention in recent years. These technologies improve transport safety, reliability and productivity by integrating with other existing technologies. In ITS systems, vehicles are equipped with short-range wireless communication technology (approximately 100 to 300 meters), acting as computer nodes and communicating with each other, vehicle-to-vehicle (V2V), or with a fixed point of any infrastructure, Vehicle-to-infrastructure (V2I). The Veicular Ad Hoc Networks (VANETs), which are networks composed of motor vehicles and infrastructures strategically positioned on the margins of streets and avenues, allow communication in real time [1] and in movement [2] between vehicles and / or infrastructure, enabling a wide variety of applications, improving safety, comfort, optimizing the time spent in traffic and serving as a tool for better management and monitoring of urban traffic, which promotes the development of smart cities [3].

The IEEE Task Force has developed an amendment to the 802.11 standard to improve it to support vehicular networks. The IEEE 802.11p standard, also known as WAVE, indicates the modes of operation and operation of the network, the technique of accessing the medium, the best modulation and encoding, the acceptable data transfer rate, among other specifications. The IEEE 802.11p is based on the 802.11a standard and has the same structure [4]. Both use OFDM transmission with the same carrier structure, however, the IEEE 802.11p standard uses a bandwidth of 10 MHz (half the bandwidth used by the IEEE 802.11a standard), in order to make the signal more robust against fading and the effect of multipath that is very strong in vehicular communications environments. The IEEE 802.11p standard operates in the 5.9 GHz band and uses the vehicle communication known as Dedicated Short Range Communication (DSRC), which is standardized by the IEEE [5]. DSRC standards are based on 802.11a, with adjustments made for low cost operations at 5.9GHz. Wireless 802.11p in-vehicle access (WAVE) is the change that allows wireless devices to communicate with each other in a high-speed vehicle environment.

The exchange of data in V2V communication systems is a field that requires solutions, tools and automated methods and the ability to facilitate early detection and even a forecast. For this reason, in recent years there has been a great growth in studies and research to evaluate the performance of VANETs [5], [6]. Some of these studies [8], [9], [10] present a proposal to use other IEEE 802.11 standards for use in vehicular environments. In [7] Tufail et al. investigates the behavior of network connections that are initiated on an IEEE 802.11g channel and discusses the possibility of using the IEEE 802.11g protocol to establish connection between fast-moving vehicles and the impact of vehicle speed. In [8] an extensive study is carried out on Tufail's work reviewing the characteristics of links formed by nodes in vehicles using IEEE 802.11a in ad hoc mode. In [9] VANET performance using DSRC and Wi-Fi Direct are performed and presented. Many studies study data delay due to the high mobility of traffic between vehicles during communication [10], [11] as communication must have a minimum of delay so that systems can receive feedback in time to make assertive decisions.

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In this article, we describe and present the results of field experiments to measure the performance of a vehicular network using the IEEE 802.11a standard. This work is the result of academic research on the realistic performance of the IEEE 802.11a standard applied to vehicular networks and the comparison with the results presented and commented. Various wireless communication parameters of the WiFi network based on 802.11a were evaluated, using the IEEE 1609 WAVE protocols for a dedicated DSRC hardware. Parameters include throughput, jitter and packet loss rate.

II. PHY Layer

Although IEEE 802.11p is based on the IEEE 802.11a standard, the first has been changed to allow greater robustness in vehicular environments where the relative speed between transmitter and receiver can be very high. Table I shows in detail the main differences in the PHY layer between the two standards. The first important difference is that the operating frequency of IEEE 802.11p is 5.9 GHz instead of 5 GHz in IEEE 802.11a. In addition, in the PHY layer, IEEE 802.11a has a bandwidth of 20 MHz, while IEEE 802.11p employs a bandwidth of 10 MHz, which results in the same modulation parameters and encoding rate, a rate of twice as much data on IEEE 802.11a.

TABLE I. Differences between IEEE 802.11a and IEEE 802.11p

Parameter	IEEE 802.11a	IEEE 802.11p
Sample rate	20 MHz	10 MHz
Chip duration	50 ns	100 ns
Number of FFT points	64	64
Number of subcarriers	52 + DC	52 + DC
Number of data subcarriers	52	52
Number of pilot subcarriers	4	4
OFDM symbol period	$T_{Symbols}$ = 80 chips = 4 ms	8 ms
Cyclic prefix	16 chips = 0.8 ms	1.6 ms
FFT symbol period	64 chips = 3.2 ms	6.4 ms
Modulation scheme	BPSK, QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM, 64QAM
Coding scheme	1/2 industry convulutional	1/2
Puncturing	optional puncturing 3/4 or 2/3	3/4 or 2/3
Available data rate	6, 9, 12, 18, 24, 36, 48, 54 Mbps	3, 4.5, 6, 9, 12, 18, 24, 27 Mbps

III. Measurement Methodology

VANETs impose a series of barriers to the analysis of the performance and viability of nodes, since the vehicular environment involves specific dynamics that are different from conventional communications. Through practical tests we can understand which applications adapt to the conditions of that network and what needs to be changed to allow the communication and operation of more applications in these environments. The important characteristics that greatly influence the performance of these applications are: the time of contact between the vehicles, the time of adaptation or reaction of the algorithms, type of connection of the network cards, as well as the speed of the buses. In this work, it is defined as the communication time between the vehicles, as the interval between the first and the last data packet received, this contact is relatively short considering the speed of the vehicles, especially when moving in opposite directions.

A. Measurement Methodology

The objective of the measurements was to obtain realistic results of communication performance between two moving vehicles. The metrics for assessing the quality of communication were: Throughput, Jitter and Packet Loss Rate. These parameters were measured at different speeds and situations. The vehicles covered a straight path of approximately 350 meters. First, the vehicles moved in opposite directions and at approximately constant speeds of 15 km/h, 30 km/h and 40 km/h. Finally, the vehicles moved in the same direction and at the same approximately constant speed of 20 km/h. The values of transfer rate, jitter and packet loss were acquired at equal intervals of 200 ms. The contact time between the vehicles varied inversely proportional to the increase in travel speed.

Transmitter and receiver measurements take a certain time to associate the communication. It was noted that the initial latency values were very high due to this association time. Therefore, the first measurements were discarded. The total distances traveled differ from the distances traveled during communication between vehicles, due to the delay time in the association between APs and computers during the generation of traffic by IPERF.

B. Hardware and Software Features

The hardware package of on board unit (OBU) consists of a computer with a Linux operating system and with the IPERF software installed, an ethernet cable and an access point (AP) with two antennas operating in the 5GHz band. The OBUs were installed in both vehicles, which from now on we will call CAR-1 and CAR-2. The APs were fixed to the roof of the vehicles, as shown in Fig. 3, and the computers, which from now on we will call NB-1 and NB-2, were accommodated internally in the rear seat of the vehicles. The receiver side runs on an IPERF server, and a client is running at the transmitter side.

To decrease the traffic of configuration data not coming from

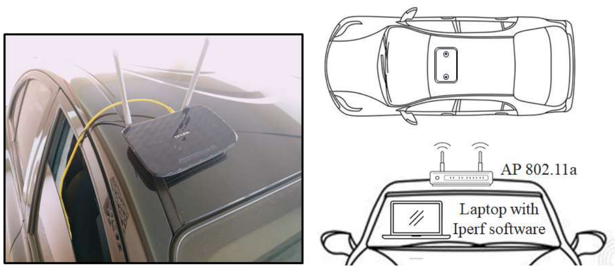

Fig. 1. On Board Unit (OBU) installed on both vehicles.

the software, the DHCP server was deactivated and the IP address of the machines was fixed. Wireless security has also been disabled. The APs Access Points were configured in order to optimize the time of association with computers e configured to work with a bandwidth of 20 MHz and channel 165 was used for the 5815–5835 MHz band, which was the operating channel closest to the DSRC channel band. The reception sensitivity was <-66 dbm and the transmission power was 23 dbm. IPERF client (NB-1) generates 1500 bytes user datagram protocol (UDP) data packets, therefore, we can call a datagram as a packet, and the number of lost datagrams is equal to lost packets. The IPERF server (NB-2) computes throughput, jitter and packet loss at an application layer.

TABLE II. EQUIPMENTS SPECIFICATION

EQUIPAMENT	SPECIFICATION
COMPUTER (NB-1)	ASUS K45A COM INTEL R CORE TMI5-3210M, PLACA PCI EXPRESS GIGABIT ETHERNET CONTROLLER. WITH LINUX OPERACIONAL SYSTEM 4.4.0-97-GENERIC X86 64 UBUNTU;
COMPUTER (NB-2)	LENOVO V310 INTEL R CORE TMI3-6100U; NETWORK ADAPTATOR QUALCOMM ATHEROS QCA9377 WIRELESS NETWORK ADAPTER OPERACIONAL SYSTEM MICROSOFT WINDOWS 10
ACCESS POINTS	TP-LINK ARCHER C20 V1, ROUTER WIRELESS DUAL BAND AC750, FIRMWARE:0.9.1 4.0 V0044.0 BUILD 160815 REL.34552N.

C. *Measurements Environment*

The tests were carried out on the campus of the State of Maranhão University (UEMA), in São Luís, Brazil. After scanning the spectrum, other IEEE 802.11 networks that could interfere with the results not were detected. The tests were carried out on a saturday day outside the university's operational hours and, therefore, there was no traffic of people or vehicles.

The avenue used is in the center of the university campus. The measurement environment was practically free of reflections and spreaders with few buildings and few trees many meters away from the transmitter. Fig. 2 shows a top view of the measurement environment.

IV. RESULTS

The performance metrics analyzed were throughput, jitter, and packet loss at each 200 ms interval, measured by NB-2 installed in the CAR-2 vehicle. The first measurements were made in a scenario where the two vehicles are moving in the same direction and at an approximately constant speed of 20 km/h. Fig. 3 shows the values of throughput, jitter and packet loss, measured during the communication interval between vehicles, which in this case was 27 seconds. The cars were kept at a distance of approximately 5 meters from each other and the distance traveled during communication was 143 m.

Fig. 2. Measurement Environment

Subsequent measurements were made in the scenario where the vehicles were traveling in opposite directions and at approximately constant speeds of 15 km/h, 30 km/h and 45 km/h. In these cases the results will be analyzed separately during the approach of the vehicles and during the separation of the vehicles. Tests with higher vehicle speeds were performed, but did not generate significant data.

Fig. 4 shows the results of throughput, jitter and packet loss measured during communication between vehicles in opposite directions for a speed of 15 km/h. The distance traveled by the vehicles was approximately 240 meters in a communication interval of approximately 29 seconds.

The communication time between the vehicles was approximately 35 seconds with a peak throughput of 9.0 Mbps during the approach of the two vehicles and at a distance of approximately 134 meters between them. In Fig. 4, the downward trend in data transfer rates is observed when vehicles cross and start to move away from each other due to the strong Doppler effect, this behavior was also observed when vehicles moved in opposite directions at speeds of 30 km/h and 40 km/h. Similar results were found in measurements made in [12]. According to these authors, it is estimated that the package delivery rate is also drastically reduced by approximately 40% to 70% after the two vehicles intersect and start to move away from each other, which is proven when analyzing the values of packet loss also presented in Fig. 4. The jitter is greater at the beginning of the displacement and at the end, when the vehicles are more distant. It is observed that the jitter values also increase a lot at the moment of crossing the vehicles. The average throughput when vehicles are approaching is much higher than when they are moving away. When vehicles are further away, transfer rates also drop due to the greater signal attenuation.

When the vehicles moved in opposite directions for speeds of 30 km/h and 40 km/h, a similar behavior was observed for the variation in throughput, jitter and packet loss observed when the speed was 15 km/h, however it was found there was a clear decrease in the average and peak value of the transfer rate when the speed was 40 km/h, both when approaching and when moving away from vehicles. This is due to the shorter contact time between vehicles and also to the greater amount of changes in the environment (multipaths, reflections and spreading of the propagated signal) generated by a higher speed, as well as

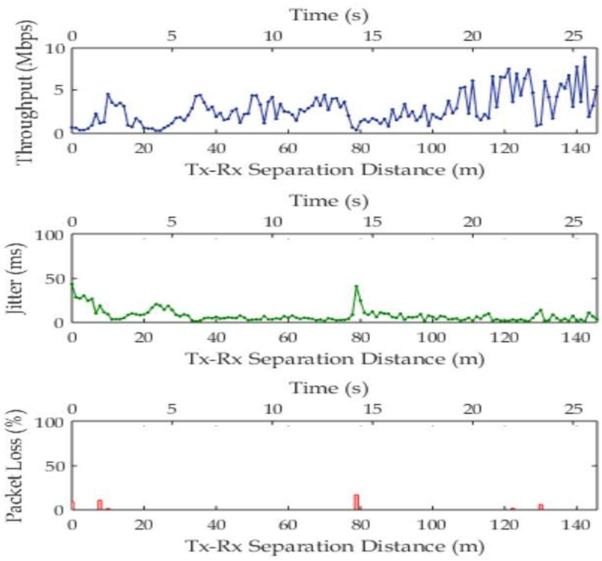

Fig. 3. Throughput, jitter and packet loss when vehicles are moving in the same direction and at a speed of 20 km/h.

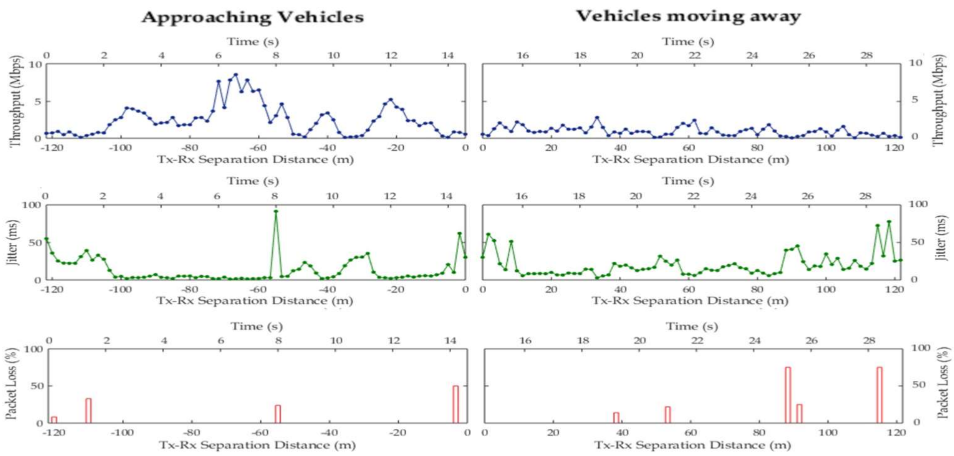

Fig. 4. Throughput, Jitter and Packet Loss when vehicles travel in opposite directions and at a speed of 15 km/h.

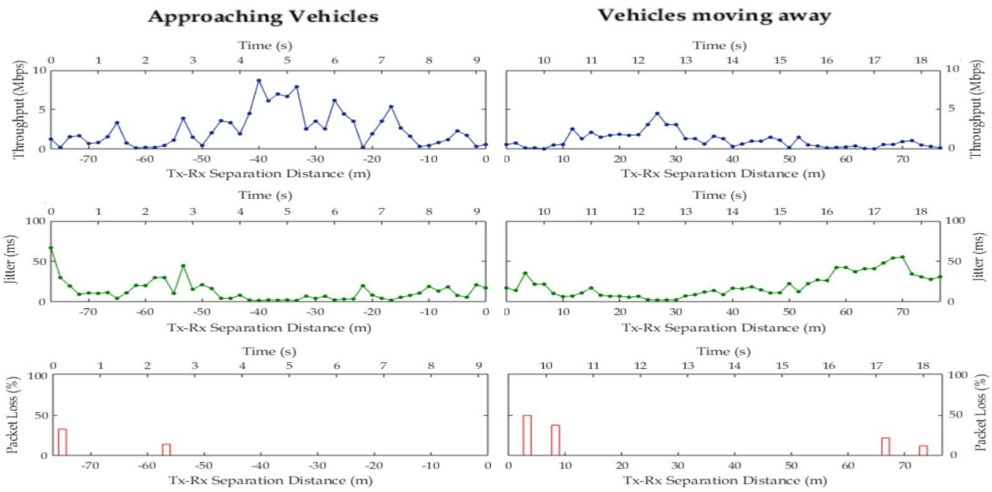

Fig. 5. Throughput, Jitter and Packet Loss when vehicles travel in opposite directions and at a speed of 30 km/h.

stronger variations of the Doppler effect. The results of throughput, jitter and packet loss for vehicles traveling at speed of 30 km/h are shown in Fig. 5.

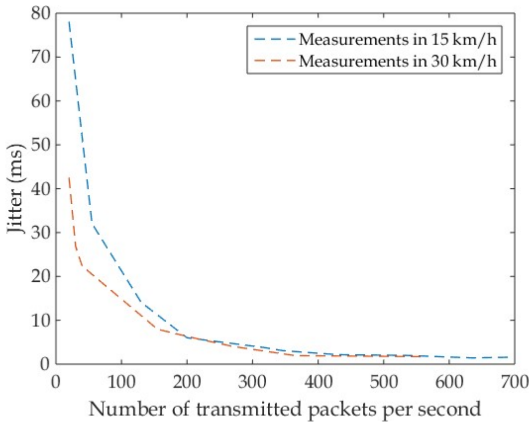

Fig. 6. Jitter versus number of packets transmitted per second

Fig. 5 shows the graphics referring to the throughput values wh en approaching and separating the CAR-1 and CAR-2 vehicles when the speed was increased to 30 km/h. In this case the distance traveled by the vehicles was approximately 160 meters and the communication time between the vehicles was only 18 seconds with a peak flow rate of 8.6 Mbps that also occurred during the approach of the two vehicles, when they were at a distance of approximately 80 meters from each other.

Fig. 6 shows the relationship between the number of packets transmitted per second and the jitter. For lower values of jitter the network is able to exchange more data. Table III then presents the main situations considering the direction of travel and the speeds of the cars.

V. Conclusions

This paper aims to investigate the quality of communication between two vehicles using IEEE 802.11a from the perspective of the main performance parameters of the network: throughput, jitter and packet loss. These values were measured in a realistic experimental scenario under conditions in which two vehicles

TABLE III. EQUIPMENTS SPECIFICATION

Measurement Scenario for CAR-1 and CAR-2 Vehicles					Throughput (Mbps)				Jitter (ms)				Packet Loss (%)			
Direction	Velocity	Distance traveled during communication	Communication Time Between Vehicles	Separation distance between vehicles	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std
Same	20 Km/h	143 m	27 sec	Fixed	0.31	9.16	2.79	1.82	1.21	43.91	7.69	7.34	0	17	0.34	1.98
Opposite	15 Km/h	240	29 seg	Approaching	0.13	9.01	2.49	2.08	1.27	91.52	13.2	16.11	0	50	1.55	7.45
				Moving away	0.06	2.82	0.93	0.59	2.92	77.91	19.75	14.97	0	75	2.85	12.79
Opposite	30 Km/h	160	18 seg	Approaching	0.12	8.64	2.47	2.23	1.32	66.8	12.57	12.39	0	33	1	5.18
				Moving away	0	4.47	1.05	0.97	1.94	55.33	19.87	14.56	0	50	2.59	9.61
Opposite	40 Km/h	62	3 seg	Approaching	0.18	1.65	1.04	0.52	6.8	66.78	18.14	19.97	0	33	4.12	11.66
				Moving away	0.12	1.53	0.58	0.46	10.20	29.82	16.58	7.01	0	14	1.75	4.94

moved in the same direction and in opposite directions at different speeds.

The minimum, the average and the peak values of throughput when vehicles moved in the same direction at a constant speed of 20 km/h were equivalent to the values when vehicles approached in opposite directions at speeds of 15 km/h and 30 km/h. In these same cases, there is a clear downward trend in transfer rates, when vehicles cross and start to distance themselves. Both at the beginning and end of the route, and at the intersection of vehicles, the jitter records higher values accompanied by greater packet losses.

During tests with vehicles moving in the same direction and maintaining a fixed distance from each other, the peak value of the data transmission rate was slightly higher than when vehicles are in opposite directions at 15 km/h. It is observed that there is a relationship between data flow and the relative speed of vehicles, when the speed increased to 40 km/h there was a significant drop in transmission rates. Fig. 6 shows that for a relative speed of 15 km/h a greater capacity for transferring packets is achieved than at a speed of 30 km/h.

Many tests and assessments related to vehicle networks, and in particular the IEEE 802.11p standard, are being carried out worldwide. With the results obtained during the field tests, it can be concluded that the transmission rates offered by IEEE 802.11a with IEEE 802.11a standard are equivalent to the transmission rates found in other experimental analyzes carried out with the IEEE 802.11p [13] standard at speeds and similar environments. Therefore, the IEEE 802.11a protocol may be used for wireless communication in V2V. However, some challenges such as vehicle speed, traffic patterns, and high mobility, affect the communication, that is, establishing communication between vehicles that approach from opposite direction. However, more field tests must be carried out considering other scenarios, with vehicles in situations of perpendicular travel to each other, and a more in-depth study of the mobile radio channel so that we can guarantee this conclusion with greater accuracy

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